*Indian J. Phys.*, **48**, 58-61 (1974)

# Electromechanical properties of aluminium doped barium titanate

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(*Received* 27 *October* 1972)

The effect of introducing different Al additions to $BaTiO_3$ transducer on the transverse coupling coefficient $K_{31}$ of vibrating rectangular rods was studied. Doping with aluminium was found to increase the coefficient $K_{31}$ and decrease the resonance frequency of the resonators. This was attributed both to an increase in the reversed proportion of 180° domains and to the increase of the looseness of $Ti^{+4}$ ions in the lattice of $BaTiO_3$ containing 0·1 wt % Al.

## 1. INTRODUCTION

The increasing general interest in the basic properties of $BaTiO_3$ as a piezoelectric substance and in its practical possibilities as a transducer material has stimulated a large number of investigations in recent years. It is often used in devices to convert electrical energy to mechanical energy and *vice versa*.

The transverse coupling coefficient was previously determined from the difference between the mechanical resonance and anti-resonance frequencies of a rectangular rod and from the radial modes of a vibrating disk under electric short and open circuit conditions respectively (Mason 1958, Mason & Jaffe 1954).

The transverse coupling coefficient, $K_{31}$, for the radial mode of vibrating disk of pure $BaTiO_3$ was previously studied (Jaffe 1958, Jaffe & Berlincourt 1965). It was found to decrease as the temperature increased until it became zero at the Curie temperature (Tawfik 1971).

The effect of adding $CaTiO_3$, $PbTiO_3$, etc., to $BaTiO_3$ on the coefficient $K_{31}$ resulted in its decrease with increasing additions (Berlincourt 1955). The increasing of the Al addition increased the coefficient $K$ (Tawfik 1969).

The present work aims at studying what kind of additions is more effective in improving the electromechanical properties of $BaTiO_3$ for the transverse mode. It is expected that the study of the effect of Al additions on the electromechanical properties of $BaTiO_3$ transducer might be of importance in producing samples fired at relatively low temperature (1200°C) and having as well a better coupling coefficient than that of the pure $BaTiO_3$ transducer fired at a relatively higher temperature (1400°C).

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## 2. Experimental Technique

*Method of measurement* :

The rectangular rods containing different aluminium additions were prepared by ceramic method, the bars were fully plated, being about 1·2 mm thick, 15 mm in length and 2 mm in width. The circuit used is shown in figure 1. The transverse coupling $K_{31}$ is determined by the known dynamic method (Mason & Jaffe 1954).

The resonance frequency $f_r$ and the anti-resonance frequency $f_a$ of the poled rods parallel to the thickness, were then measured to obtain $K_{31}$ by

$$K_{31}^2/(1-K_{31}^2) = \frac{\pi}{2} \cdot \frac{f_a}{f_r} \tan \frac{\pi}{2} \cdot \frac{\Delta f_a}{f_r}$$

where $\Delta f = f_a - f_r$.

The temperature of the sample was raised and resonance and anti-resonance of the resonator was recorded at each temperature, *viz.*, 30°, 40°, 50°, etc., and the coefficient $K_{31}$ was calculated.

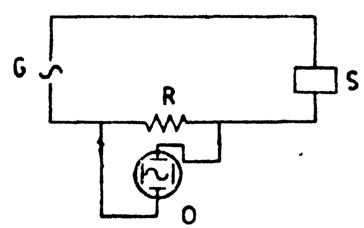


Fig 1. Circuit for measuring coupling factor. *G*—signal generator, *R*—resistance 15*k* ohm; *O*-pulse oscilloscope, *S*—sample.

## 3. Experimental Results and Discussion

### 3.1. *Dependence of the transverse coupling coefficient $K_{31}$ on Al additives*

An increase of the transverse coupling $K_{31}$ as the aluminium additives were increased was observed (see figure 2).

This increase is attributed to an increase in the degree of reaction which was verified from dielectric measurements in a previous work (Tawfik 1969). Consequently a larger proportion of 180°—domains are thus reversed in the poling process, which gives rise to a higher net polarization (Amin & Tzwfik, to be published). Besides, the strain effects caused by Al additives at least in the vicinity of these sites where $Ti^{+4}$ ions were replaced by $Al^{+3}$ ions resulted in an harmonic oscillations of $Ti^{+4}$ ions. This view point implied that introduced Al atoms created strains, and the potential energy of the $Ti^{+4}$ ions changed resulting in the increase of the looseness of the $Ti^{+4}$ ions in the lattice. The looseness of $Ti^{+4}$ ions helped the $BaIoO_3$ transducer to be piezoelectrically excited earlier than the pure $BaTiO_3$ fired at 1400°C.

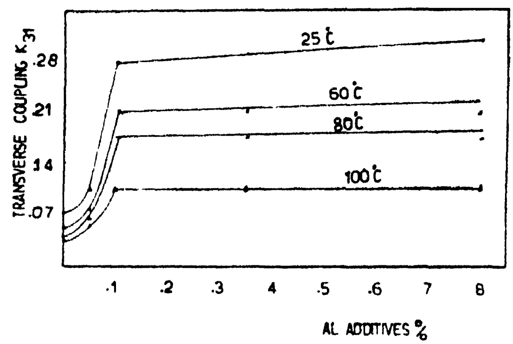


Fig. 2. Effect of temperature on dependence of transverse coupling $K_{31}$ on Al additives.

### 3.2. *Temperature dependence of the transverse coefficient $K_{31}$*

The observed decrease of the coupling coefficient $K_{31}$ with temperature (see figures 3, 4) is directly related to the decrease in the polarisation of the sample. At Curie temperature, the coupling coefficient $K_{31}$ has zero value.

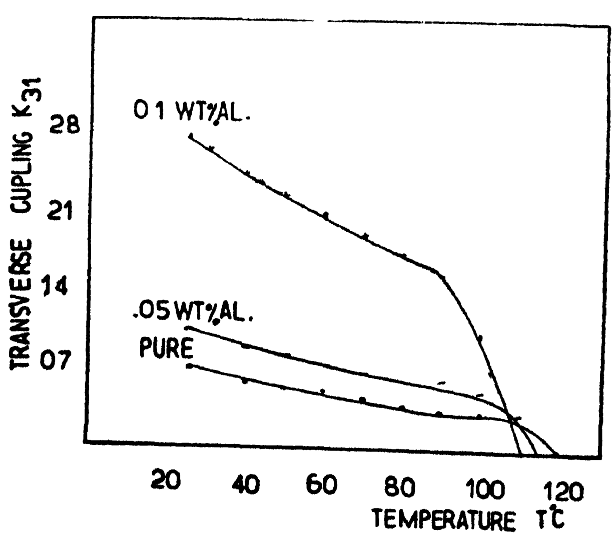


Fig. 3. Effect of Al additives on temperature dependence of transverse coupling $K_{31}$.

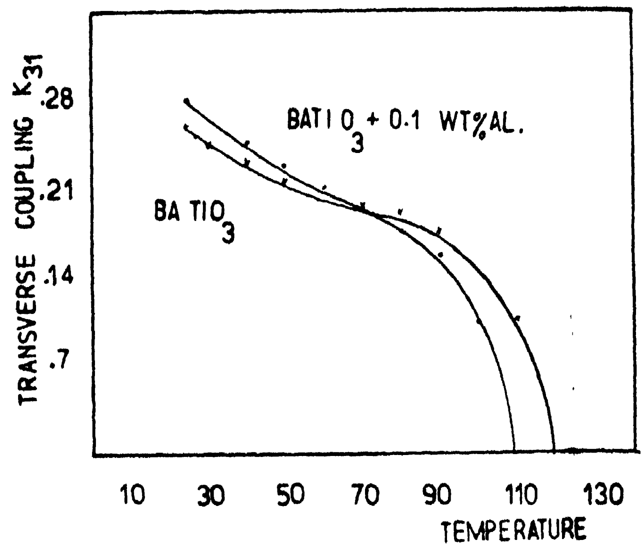


Fig. 4. Temperature dependence of transverse coupling $K_3$ for $BaTiO_{31}$ fired at 1300eC, and $BaTiO_3$ containing 0·1 wt% Al and fired at 1200°C.

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